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ABSTRACTS

Effects of Alongshore Variations in Coastline Geometry and Bottom Topography on Coastal Flows

THE ROLE OF HEADLAND WIND JETS IN THE ANNUAL CYCLE OF THE CALIFORNIA CURRENT SYSTEM

Robert L. Haney (Dept. of Meteorology, Naval Postgraduate School, Monterey, CA)

Mountainous headlands along the west coast of North America distort the atmospheric boundary layer airflow, producing patches of enhanced upwelling and downwelling favorable winds downstream of each headland (D. Rogers, pers. comm.; see also Enriquez and Friehe, JPO 1995). The effects of such headland-induced wind patches on the coastal ocean circulation are studied by means of two long-term simulations of the annual cycle in the California Current (CC) using the DieCAST regional model (e.g., Dietrich, DAO in Press). One of the simulations uses a climatological annual cycle of wind stress forcing (Hellerman and Rosenstein, JPO 1993), while the other simulation includes an additional wind stress enhancement near each coastal headland that is representative of that observed. Using climatological forcing, the model reproduces many of the main features of the observed annual cycle of the CC (Strub and James, JGR submitted) including the separation of the coastal jet from the coast in late summer and its replacement by poleward currents near shore in autumn and winter. Coastal eddies form primarily off the major headlands, especially Cape Mendocino and Point Arena. The surface eddy kinetic energy is in the range of that observed and it undergoes a seasonal cycle with a phase that varies with distance from shore similar to that observed (Kelly et al., JGR submitted). The additional wind forcing by the headland wind jets produces both local and remote changes to the above annual cycle, and these will be presented and discussed at the meeting.

ON THE EFFECTS OF COASTLINE IRREGULARITIES IN EBCS

Mary L. Batteen, Eric J. Buch, and Ming-Jer Huang (Dept. of Oceanography, Naval Postgraduate School, Monterey, CA)

A high-resolution numerical model is used to study the effect of coastline irregularities in the wind-driven California Current System (CCS) and the Portugal Current System (PCS) and in the thermally driven Leeuwin Current System (LCS). In the CCS and PCS, irregularities in the coastline geometry are shown to be important for anchoring upwelling and filaments, as well as for enhancing the growth of filaments and eddies. Cyclonic eddies tend to form in the coastal indentations in the vicinity of capes, while anticylclonic eddies tend to form in the coastal indentations between capes. In the CCS, the region of Cape Blanco is identified as the location where the coastal, equatorward flow off Oregon leaves the coast, while in the PCS, the coastal equatorward flow leaves the coast near Cabo de Sao Vicente, where the Portugal Current changes direction. In the LCS, maximum current velocities occur at Cape Leeuwin, where the Leeuwin Current changes direction, while offshoots, anticyclonic meanders and eddies occur at preferred locations: in the vicinity of coastal indentations, and at Cape Leeuwin. Cold, cyclonic meanders and eddies form from the limbs of the warm, anticyclonic eddies, and propagate westward with the anticyclonic eddies as eddy pairs.

LAYERED MODELS OF COASTAL JET SEPARATION AT CAPE BLANCO

Andy Dale and Jack Barth (College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR)

During 1994 and 1995 extensive observations were made of the current and density structure of the upwelling jet off the Oregon coast. The equatorward jet is established following the spring transition when winds become predominantly upwelling favorable. Early in the upwelling season the jet remains attached to the coast as it rounds Cape Blanco (e.g. May 1995). Later, as its total transport increases, it may meander and form eddies (e.g. August 1994) or separate entirely from the coast at the Cape, continuing south in deep water (e.g. August 1995).

There has been much work on layered models of inertial currents with alongshore uniformity assumed. Of particular relevance here are cases where multiple structures exist that are consistent with one another in terms of their transport and potential vorticity structure in each layer. One such structure could conceivably distort into another by passing through a region of complex dynamics (such as close to Cape Blanco). The analogy with the Cape Blanco observations is clear when such a transition is from an attached to a separated state. This is effectively a hydraulic control mechanism.

Woods (1988) has shown that multiplicity of structures can occur in a case with a flat bottom and idealised potential vorticity structure. However, multiple structures only occur when the layer transports lie in a very restricted range. Results will be presented of Woods' model with the addition of bottom topography, which greatly increases the range of layer transports that permit multiple structures. Further calculations have been made using observed potential vorticity distributions and realistic topography for the region of Cape Blanco.

The addition of coastline curvature is a relatively straightforward modification to the two-dimensional problem. It leads to a distortion of the cross-shore structure of the current and in some cases causes a layer interface to outcrop at the surface. Such a process may initiate the separation of a jet or its transition to a second structure. The effect of coastline curvature has been calculated for the upwelling jet in its attached state north of Cape Blanco.

Biological Implications of the Effects of Alongshore Variations in Coastline Geometry and Weekly Fluctuations in Upwelling Winds on Coastal Flows

Louis W. Botsford and Lance Morgan (Dept. of Wildlife, Fish and Conservation Biology, University of California, Davis, CA)

Temporal and spatial patterns in coastal circulation can have a dominant effect on harvested populations, especially through effects on planktonic larvae in the spring. Alongshore variations in topography lead to larval retention zones, such as upwelling shadows, which allow populations to persist in spite of equatorward and offshore flows. Relaxations in upwelling winds redistribute retained larvae in specific alongshore patterns. In this paper we show how these patterns affect the northern California red sea urchin fishery. Alongshore differences in frequency of recruitment along the coast lead to differences in fishery productivity, tolerable effort, and apparent harvest rate.

Bifurcation of a Coastal Current at an Escarpment

George F. Carnevale (Scripps Institution of Oceanography, La Jolla, CA), F. Crisciani (National Research Council, Trieste, Italy), S.G. Llewellyn Smith (Scripps Institution of Oceanography, La Jolla, CA), and R. Purini (Institute for Atmospheric Physics, Rome, Italy)

An exact analytic solution to the problem of stationary quasi-geostrophic coastal flow over a step is presented. An approximate solution to the shallow water problem is also presented. These solutions show that the flow behaves very differently depending on whether the geometry is 'right-handed' or 'left handed,' independent of the direction of flow of the coastal current. This handedness is defined such that 'right-handed' means that the coast is on the right when looking from deep to shallow (in the northern hemisphere). It is shown that only in the right-handed geometry is it possible to obtain a steady offshore current along the step. The implications of these analytic stationary solutions for the dynamically evolving coastal flow over a step are examined through simulations of quasi-geostrophic flow. The relevance of this work is discussed in light of recent results from laboratory experiments.

Subtidal Currents Over the Central California Slope: Evidence for Spatial and Temporal Variations in the Undercurrent and for Local Wind-Driven Currents Over the Outer Slope

Marlene Noble (U.S. Geological Survey, Menlo Park, CA) and Steve Ramp (Office of Naval Research, Washington, D.C.)

In February, 1991, an array of 6 current-meter moorings was deployed for one year across the central California outer shelf and slope. The main line of the array extended 30 km offshore of the shelf break, out to water depths of 1400 m. A second, more sparsely-instrumented line that extended 14 km offshore of the shelf break was located 30 km northwest of the main line. This northern line spanned water depths similar to those along the main line because the bottom slope was much steeper. A strong, surface-intensified, poleward flow with speeds up to 40 cm/s was seen along both lines of the moored array down to water depths of 800 m. This spatially-coherent flow represents the California Undercurrent over this region of the slope. In general, the strong alongslope currents seen crossing the southern line were weaker or absent at the northern line. We suggest that topographic constraints tended to force

the energetic undercurrent offshore of the northern measurement sites; the slope of the topography steeped too abruptly to allow the strong flow to follow isobaths. When current velocities lessened, the undercurrent could follow the isobaths and a coherent flow pattern was seen across both lines in the array. The undercurrent was not affected by local winds or by fluctuations in the alongshore pressure-gradient. A strong seasonal pattern was also not evident. However, the alongshelf wind did force local surface currents to flow along the slope, parallel to the wind field, down to depths of 400 m and out to distances of 2 Rossby radii past the shelf break. Wind-driven currents were weaker than flows in the undercurrent, 3-4 cm/s per dyne/cm2 wind stress, but were comparable to wind-driven current amplitudes seen over the mid shelf, 5-6 cm/s per unit wind stress. Equatorward alongshelf winds also caused water from 200-300 m over the slope to upwell onto the shelf and surface water to move offshore.

BOUNDARY RESPONSES OF A NESTED SANTA BARBARA CHANNEL MODEL

David E. Dietrich and Avichal Mehra (MSU Center for Air Sea Technology, MS) and Robert A. Hale (Dept. of Meteorology, Naval Postgraduate School, Monterey, CA)

The Santa Barbara Channel (SBC) is modeled using one minute (<2 km) resolution with an improved low dispersion DieCAST ocean model. Time dependent open boundary conditions are prescribed from a five-minute resolution California Current (CC) DieCAST model simulation. The nesting strategy is simple but effective. With a single coarse grid interval overlap, no sponge layer is needed. The strongly transient CC model coastal jet response to observed semi-permanent 40 km wind jets off the CC headlands leads to similarly strong SBC model response. Animated results show: much small-scale eddy activity, including jet spurts around edges of the SBC basin and Channel Islands; significantly ageostrophic dynamics in the surface layer and in sharp gradient regions below; major eddy growth is appropriately correlated with a clearly visible divergent flow component; and simulated Lagrangian tracer particle trajectories are strongly affected by time variations in the SBC flow.

COLUMBIA RIVER ESTUARY AND PLUME DYNAMICS UNDER VARYING RIVER AND OCEAN CONDITIONS: INSIGHTS FROM AN EMERGING NOWCAST-FORECAST SYSTEM

Antonio Baptista, Salil Das, Philip Pearson, Mike Wilkin, Cole McCandlish, Paul Turner, David Jay, Ming Qi, and Neetu Nangia (Center for Coastal and Land-Margin Research, Oregon Graduate Institute, Portland, OR)

Novel nowcast-forecast systems are posed to provide significant insights on estuarine dynamics. As an early proof of concept, we are using CORIE (Baptista et al. 1997), an emerging nowcast-forecast system for the Columbia River, to investigate the sensitivity of the baroclinic circulation in the Columbia River estuary and plume to varying river and ocean forcing.

The first part of the presentation will briefly review the status and functionality of CORIE. Active components include a real-time data acquisition and management system with both moored (http://www.ccalmr.ogi.edu/CORIE/network) and vessel-based (http://www.ccalmr.ogi.edu/CORIE/-cruises/) monitoring capabilities, and a range of hydrodynamic and transport numerical models based on unstructured grids. Models have been run primarily in hindcast mode, but early forecasts will also be presented.

The second part will concentrate on the joint interpretation of field data and early modeling results for selected month-long periods in 1996 and 1997. Focus will be on the varying dynamics, with river and ocean conditions, of the circulation and density structure of the lower estuary and (modeling only) of the plume. Issues of particular interest are lateral exchange mechanisms between the north and south channels, eddy patterns in the bar and the plume, and extent and orientation of the plume.

MONITORING COASTAL UPWELLING FROM THE CALIFORNIA SURFZONE

Alex van Geen, R. Takesue, and M. Sapanara (Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY) and S. R. Connolly (Biology Department, Stanford University)

Nutrient and salinity samples were collected from the surfzone every month from March 1996 through May 1997 at nine locations, between San Simeon (35.5° N) and Cape Mendocino (40.4° N), selected for a study of barnacle and mussel recruitment dynamics. The overall pattern of variations in nutrient concentrations in the surfzone appears to be remarkably consistent with large-scale forcing, both temporally and spatially. The annual range of nitrate concentration varied from 4-19 μM at the southern end of the transect to 6-34 μM at the northern end. The extrema were reached in late winter and late spring, respectively. The spring transition of 1997 preceded the spring transition of 1996 by about two months. Annually averaged concentrations gradually increased over the ~500 km length of the transect from 9±6 μM at San Simeon to 22±11 μM at Cape Mendocino. This pattern is consistent with climatology showing a general decline in the intensity of equatorward winds south of Cape Mendocino during the upwelling season.

These observations raise some questions regarding the processes that control surfzone nutrient concentrations. Maximum nitrate (34 μM), silicate (51 μM), and phosphate (2.5 μM) concentrations that were measured are consistent with the composition of subsurface water at 300 m depth, ~100 km from the coast. How does this water mass reach the surfzone if surface water nutrient concentrations over the shelf typically do not reach such elevated levels? Local wind forcing is highly variable on diurnal to weekly time scales. Why does the composition of surfzone water appear to be determined by forcing on spatial scales on the order of 100 km and temporal scales on the order of a month? On the basis of the chemical tracer data, we propose a pattern of onshore bottom flow that originates at the edge of the continental shelf and extends as far as the surfzone, even when local wind forcing is relatively weak. This circulation pattern would be consistent with the apparent buffering of fluctuations in the composition of surfzone water relative to local changes in wind forcing and coastal topography. Is this a physically plausible explanation?

INTERNAL SOLITARY WAVES ON A SHALLOW SHELF

Dariusz. Bogucki and L. G. Redekopp (Dept. of Aerospace Engineering, University of Southern California, Los Angeles, CA)

Remote sensing of oceanic waters above the shelf region in recent years has revealed that packets of propagating internal solitary waves (ISWs) are common, frequent and prominent features. It is becoming clear that these ISWs also have an important dynamic effect on the vertical mixing occurring in the water column, even to the extent that they can suspend and transport benthic sedimentary material, yielding vertical diffusion coefficients as high as 10^{-2}. In this presentation we will report on direct observations of significantly increased concentration of sedimentary particulates in the water column following the passage of a packet of ISWs propagating along a strongly stratified bottom layer on the California shelf. We will also describe studies of some modeling efforts, which show significant promise for providing an understanding of a mechanism whereby ISWs act as efficient sources of mixing within the benthic boundary layer. One mechanism for which we have definitive results involves a topographic resonance between coastal currents and bottom topography, giving rise to ISW packets which propagate against the oncoming current and create a boundary layer structure in the footprint of the packet whose spatio-temporal coherence provides a efficient “bottom pump.” Other cases are concerned with the footprint of large amplitude waves containing recirculating eddies and the reflection of long waves from the sloping bottom. In each case the imprint of the ISW packet on the bottom boundary layer is favorable for benthic resuspension.

Optical Properties and Processes of the Eastern Pacific

OPTICAL EFFECTS OF A NEAR-SHORE INTERNAL WAVE

Robert A. Maffione (Hydro-Optics, Biology, and Instrumentation Laboratories, Moss Landing, CA)

One of the more prominent and complex bays along the eastern rim of the Pacific is Monterey Bay, which extends 40 km wide at the mouth and extends inland approximately 20 km, covering an area of about 800 square km. During the upwelling season, which generally lasts from March to September, nutrients are advected into the bay via a counterclockwise current driven by the southerly California current, and also by upwelling and shoaling of on-shore currents through the Monterey Submarine Canyon. These upwelling circulation patterns drive intense phytoplankton blooms with often highly complex spatial distributions within the bay. Their vertical distributions are particularly interesting because they often form thin, yet dense scattering layers. Using a submersible remotely-operated vehicle instrumented with several types of sensors for measuring inherent and apparent optical properties, as well as temperature, salinity, and pressure, we were able to record the modulation of an optically dense scattering layer by an internal wave. This event was recorded during the morning of August 15, 1995, at the location 36˚ 55.074 min. W, 122˚ 0.221 min. N. Bottom depth was 30 m, and the average depth of the scattering layer was approximately 7.5 m., oscillating between 5 and 10 m, peak to trough. The fundamental period of the internal wave was varied between 15 and 18 minutes (the oscillations were clearly not purely harmonic). These internal wave parameters matched the calculations from both the optical measurements and density measurements. At a fixed depth, modulation of the scattering layer caused changes in the IOP’s by as much as 180%, most notably the beam attenuation coefficient in the spectral range from 440 to 590 nm. Curiously, however, the largest percent changes were seen in the upwelling radiance in the blue-green spectral range. At 590 nm, for example, the upwelling radiance changed periodically by a maximum of 300%. Radiative transfer calculations using Hydrolight revealed that the optical effects of this internal wave could easily have been detected and characterized by an airborne hyperspectral radiometer. The periodic changes in the water leaving radiances caused by the internal wave modulation were between 7% and 20%, depending upon wavelength and viewing angle.

THE VARIATION AND DEPENDENCE OF OPTICAL PROPERTIES ON HIGH FREQUENCY INTERNAL WAVES IN A NEAR-SHORE ENVIRONMENT

Kieran O'Driscoll, W. Scott Pegau, and Thomas M. Dillon (College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR)

A preliminary analysis is presently being conducted on data collected close to shore during the LOE (Littoral Optics Experiment) of October 1995. The data was collected from 17 sites over a period of 11 days. The instrument array included CTD and ac9's. These sites cover an area of about 4 km squared, close to shore at Oceanside, CA. The stations vary in depth from about 6 m to 35 m. Initial analysis of the data set shows a very strong correlation between the optical properties and the physical properties attainable from the CTD, particularly density and temperature. This presentation shows various observations correlating physical and optical properties within the pycnocline and particularly in the nepheloid layer. The main mechanism being presented for these correlations is the propagation of high frequency internal waves. Preliminary results relating variability of optical properties with other physical parameters and their relation to internal waves and other forcing mechanisms are presented. We also present results showing the effects of these internal waves on the optical field as they propagate from stratified (offshore) waters into the shallow homogeneous surf zone.

RAPID, HIGH-RESOLUTION, OPTICAL AND HYDROGRAPHIC SURVEYS USING SEASOAR

Jack Barth, Darek Bogucki and P. Michael Kosroh (College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR)

As part of the Coastal Mixing and Optics program, optical attenuation and absorption data were collected together with CTD data using SeaSoar from 14-August to 1-September 1996 and from 25-April to 15-May 1997. The study region was centered on 40.5˚ N, 70.5˚ W on the continental shelf south of Cape Cod, Massachusetts. The water column was sampled from the surface to within 10 m of the bottom by towing SeaSoar at 8 kts so that horizontal resolution ranged from 1/3 to 1 km. Attenuation and absorption were measured continuously at nine wavelengths using a WETLabs ac9 mounted on SeaSoar with the ac9 intakes located in close proximity to dual-sensor Seabird CT sensors. A brief review of technical details concerning the production of high-quality optical data using an ac9 on SeaSoar, e.g. time-dependent lagging of optical and physical data, will be presented.

Three mapping strategies were employed during both the summer and spring cruises: large-area, 70x80 km shelf-slope surveys to define regional distributions; small-area 25x25 km boxes centered on a moored array in 70-m of water and also the location of concurrent vertical profiling conducted from a second, stationary research vessel; and a butterfly survey pattern with a leg along the 70-m isobath to define scales of variability alongshore. The optical properties of major water masses and the spatial distributions of those properties will be discussed in relation to mesoscale hydrographic and velocity features. The vertical structure of the optical fields and horizontal variability of that structure will be related to physical characteristics of the water column. For the summer 1996 data, emphasis will be placed on: 1) distributions of chlorophyll at the base of the pycnocline; 2) patterns of near-bottom suspended sediment; and 3) the optical and physical signature of large-amplitude internal solitons. For the spring 1997 data, the emphasis will be on changes in water column physics and optics due to surface forcing and advection.

BIO-OPTICS AND REMOTE SENSING OF A MASSIVE RED TIDE OFF SOUTHERN CALIFORNIA

Mati Kahru and B. Greg Mitchell (Scripps Institution of Oceanography, La Jolla, CA)

Bio-optical characteristics of a massive red tide in March, 1995 off Southern California are compared to a “baseline” of a large data set of bio-optical measurements from the California Cooperative Fisheries Investigations (CalCOFI) covering the Southern California Bight. The red tide was initially dominated by a dinoflagellate Lingulodinium (Gonyaulax) polyedra but was replaced in April by a hetero-trophic dinoflagellate Noctiluca scintillans. The red tide phytoplankton had unusually strong absorption in the 300-400 nm spectral range and a practically linear increase in the absorbance with the increase of chlorophyll a concentration (chl-a) of 2 orders of magnitude (from 1 to 150 mg m^{-3}). It is shown that this type of red tides can be remotely detected by using the increased absorption and thus reduced remote sensing reflectance (Rrs) in the 300-400 nm spectral range. The anomalously high ultraviolet (UV) absorption was caused by the mycosporine-like amino acids (MAAs) that are believed to provide photoprotection against UV light. The difference in Rrs of the red tide and “normal” California Current phytoplankton diminished regularly with increasing wavelength from 340 to 443 nm. Ratios of Rrs at 340 nm and 412 nm (or 340 nm and 443 nm) provided the best differentiation of the red tide stations dominated by dinoflagellates from the “normal” CalCOFI samples, usually dominated by diatoms at high chl-a. Using Rrs (380) instead of Rrs (340) in the reflectance ratio was almost as good in separating the red tide at chl-a levels > 2 mg m-3 but was inferior at lower chl-a. The observed increase in absorption by the dissolved organic materials in the red tide was relatively less important compared to the huge increase in particulate absorption. The Japanese Global Light Imager (GLI) sensor scheduled for launch on the ADEOS II platform in 1999 has, among others, the wavelength band at 380 nm that has not been available on any other ocean color satellite. If the signal to noise ratio of the 380 nm band is adequate and atmospheric correction can be done to retrieve the dynamic range of the water leaving radiance then it might be possible to use either Rrs(380)/Rrs(412) or Rrs(380)/Rrs(443) to detect red tides. The presence of the 380 nm band, combined with the 250 m spatial resolution, makes the GLI a potentially powerful tool for monitoring coastal zones for harmful algal blooms.

SPECTRAL RELATIONSHIPS OF THE INHERENT OPTICAL PROPERTIES IN THE CENTRAL GULT OF CALIFORNIA

W. Scott Pegau, Andrew H. Barnard, and J. Ronald V. Zaneveld (College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR)

We have collected optical data during two cruises in the Central Gulf of California. We investigate the similarities and differences of the spectral shape of the inherent optical properties IOP for the two sampling seasons. We then compare the spectral signatures associated with the Gulf of California to data collected from other regions to determine the need for regional and seasonal models of the IOP for inversion of remote sensing data. We find differences in the range of magnitude IOP collected during each cruise, with some differences in the spectral shape. The spectral relationship of the particulate material also differs from other regions of the world oceans. The differences between the local and global spectral relationships provide an indication of the important types of particles in this region, and the usefulness of regional models of the IOP.

WHAT DO TRANSMISSOMETERS C?

James K. Bishop (School of Earth and Ocean Sciences, University of Victoria, Victoria, B.C.)

We have investigated the relationships between beam attenuation coefficient, C, at 660 nm using Sea Tech transmissometers and particulate matter concentrations determined by the Multiple Unit Large Volume in-situ Filtration System (MULVFS) during simultaneous casts. The MULVFS permits collection of particles, split in-situ into >53, 1-53 and <1 um size classes, from volumes of seawater up to 16,000 L. Samples have been analyzed for all major, minor and trace particulate matter constituents. Our analysis of results from the equatorial Pacific, NW Atlantic, and subpolar NE Pacific shows that beam attenuation coefficient and particulate organic carbon, POC, are the best correlated of all particulate matter properties. The relationship appears to be virtually independent of ocean environment, season, or depth sampled. Our results suggest that the transmissometer can provide a quantitatively useful estimate of POC to better than 10% accuracy and systematically to better than a few percent. This opens the opportunity for deploying transmissometers from platforms other than ships to characterize the high frequency (diurnal and longer timescales) variability of particulate organic carbon within the upper layer of the ocean. Furthermore, we have provided an improved basis for interpretation of a vast body of beam attenuation coefficient measurements made in the oceans over the past two decades. The universality of the C vs. POC relationship is not yet fully understood and will be explored in ongoing analysis of MULVFS data and as part of efforts to collect new MULVFS samples from polar seas.

THE HYPERSPECTRAL REMOTE SENSING TECHNOLOGY PROGRAM

Curtiss O. Davis and Paul W. Bissett (Code 7212, Naval Research Laboratoy, Washington, D.C.)

A wide variety of applications of imaging spectrometry have been demonstrated using data from aircraft systems. Based on this experience we have developed requirements for a satellite imaging spectrometer system to best characterize the littoral environment, for scientific and environmental studies and to meet Naval needs. This paper describes those requirements and the resulting Hyperspectral Remote Sensing Technology (HRST) program. The HRST spacecraft has a Coastal Ocean Imaging Spectrometer (COIS) with adequate spectral and spatial resolution and high signal to noise to provide long term monitoring and real-time characterization of the coastal environment. It includes on-board processing for rapid data analysis and data compression, a large volume recorder, and high speed downlink to handle the required large volumes of data. A primary goal of the HRST program is to develop high resolution coupled physical bio-optical models of the coastal environment using the COIS data for the development and validation of those models.

THE NRL COBALT PROJECT

John C. Kindle (Code 7331, Naval Research Laboratory, Stennis Space Center, MS), Paul W. Bissett, and Curtiss O. Davis (Code 7212, Naval Research Laboratoy, Washington, D.C.)

This presentation provides a brief description of the modeling components of the new NRL ARI "Coupled Biophysical-dynamics Across the Littoral Transition" (CoBalt). The primary objective of project is to understand the physical dynamical influences on the biodynamical processes and optical properties of the North Pacific eastern boundary current regime. The two major components of the proposed study are numerical modeling and remote sensing. The ocean circulation models will be: 1) the Princeton West Coast (PWC) model currently being tested for operational use at FNMOC and 2) the NRL layered model with a grid resolution of 1/8th to 1/16th degrees. The PWC model is a sigma coordinate formulation that extends from 30˚ N to 49˚ N and from the coast to 135˚ W with a grid resolution of 1/12 degrees. The model utilizes 30 levels in the vertical to resolve the surface and bottom boundary layers over the shelf. The model also includes monthly varying, fresh water runoff from seven rivers that impact the model domain. The PWC model is embedded within the NRL global 1/4 degree layered model from which it receives its boundary conditions; this provides for the inclusion of externally forced events such as upstream variations of the California Current and Kelvin waves excited along the west coast south of the model domain and in the equatorial regions.

Multi-component bio-optical models will be incorporated into the two complementary ocean circulation models. The bio-optical components will extend the recent work of Bissett, et al. (1994, 97). The Bissett, et al. (1997) bio-optical model is a one dimensional ecological system model which models the dynamics of a size fractionated phytoplankton community in response to changes in wind stress, light, grazing stress and nutrient availability. Model outputs include full spectral optical properties, such as upwelling radiance, which can be directly compared to OCTS, SeaWIFS, AVIRIS and PHILLS data. The model was developed and tested for the open ocean, but includes large fast growing diatoms and grazers that are characteristic of the coastal ocean, and thus is ideally suited to this application. Key questions to be addressed include: The importance of variations in nutrient supply and light limitation as a function of coastal runoff, and the relative importance of coastal upwelling, runoff and ocean currents in controlling phytoplankton growth and ocean optical properties. The present version of this model (EcoSim) is physically driven, and is designed to take the output from a high resolution physical circulation model as input to produce a three dimensional ecological simulation and output the resulting optical conditions.

The Subarctic Pacific

ON TOPOGRAPHY'S ROLE IN CROSS-SHELF-BREAK EXCHANGE

Susan Allen and E. Eurin (Dept. of Earth and Ocean Sciences, University of British Columbia, Vancouver, B.C.), Greg Holloway (Institute of Ocean Sciences, Patricia Bay, B.C.)

Potential vorticity conservation places a strong constraint on low-frequency flow to follow bathymetric contours. Steep gradients of planetary f/H near shelf break are partially responsible for minimal cross-shelf-break exchange and the associated along-shore fronts. However, the topography of the shelf and slope is not uniform along-shore and is, in many places, quite convoluted. The variation of the topography may enhance cross-shelf exchange under upwelling or downwelling favourable winds. It certainly will determine the position and structure of this flow.

The effect of a single canyon will be discussed to illustrate these two points. Then a discussion of the effects of random topographic variation will be presented.

TIDAL SIGNAL REMOVAL AND SEA LEVEL CHANGE IN THE NE PACIFIC OCEAN FROM 4 YEARS (OCTOBER 1992–SEPTEMBER 1996) OF TOPEX/POSEIDON DATA

M.G.G. Foreman, W.R. Crawford, and Josef Y. Cherniawsky (Institute of Ocean Sciences, Sidney, B.C.)

Much of the sea level variability in the Topex/Poseidon (TP) altimeter data is due to tidal signals, aliased with 10-day satellite orbit repeat period. TP sea-level data, distributed by the NASA GSFC Pathfinder project (http://neptune.-gsfc.nasa.gov/~krachlin/opf/descriptions.html) or from other sources, undergo state-of-the-art geophysical corrections. These include ocean tide removal (the largest of the standard corrections) using a global tidal model (Schrama and Ray, JGR, 99, 24799, 1994) supplemented at high-latitudes with the FES94.1 model (LeProvost et al., JGR, 99, 24777, 1994).

These large scale models do a reasonable job of removing tides in the deep ocean, but they are not adequate in shallow seas, which usually shows up as significant intra-seasonal signal at about 60 day period near the boundaries. We attempt to do a more accurate tidal calculation and removal from the TP sea-level data using harmonic constants calculated from TP data alone. Comparison to the standard Pathfinder sea level shows that these enhancements result in much smaller tidal residuals.

The corrected TP data show a general decrease in sea-level in NE Pacific during this 4-year period and significant seasonal and interannual variability. Such data are not available from other sources, except for coastal tide gauges.

How do Fe and N Limitation Differ in their Control of Primary Production and Phytoplankton Competition

Paul J. Harrison (Dept. of Earth and Ocean Sciences, University of British Columbia, Vancouver, B.C.), Philip Boyd (NIWA, Dept. of Chemistry, University of Otago, Dunedin, New Zealand), and Diana Varela (Dept. of Earth and Ocean Sciences, University of British Columbia, Vancouver, B.C.)

The focus of biological oceanographic studies in the subarctic Northeast Pacific has been at Stn P (50˚ N, 145˚ W) and along line P (a transect from the coast of Vancouver Island to Stn P) for the last 4 decades and during this period, basic measurements of T, S, nutrients, chl, primary productivity and zooplankton were made. In the 1980s the SUPER project focussed on Stn P and made more detailed measurements of the photic zone biology. For the past 5 years, Phase I and II of CJGOFS has made 13 cruises along line P to Stn P and broadened the biological coverage to include winter cruises, Fe limitation, size-fractionated primary production, microzooplankton, heterotrophic bacteria, extensive mid water column studies on the microbial loop, particle flux and remineralization and sediment trap samples. Therefore, the station P area is the most intensively studied high nitrate low chlorophyll (HNLC) area in the world. These historical (4 decades) and extensive (13 cruises) data sets provide modellers with an unique opportunity to make new advances in our understanding of the biogeochemistry of the carbon and nitrogen cycles in this Fe-limited area.

The coastal ocean is characterized by the classical seasonal cycle of spring and fall diatom blooms and primary production is controlled by nitrogen. The fate of the phytoplankton in this region is primarily by sedimentation to depth by large diatoms associated with the spring and fall blooms and a recycling system (via nanophytoplankton and microzooplankton grazing) during other seasons.

The open ocean stations display low seasonality in biomass, and production and are dominated by small cells. The low seasonality is controlled by a shallow winter pycnocline permitting close coupling year round between the nanophytoplankton and the micrograzers. Low iron supply prevents the occurrence of diatom blooms observed in the coastal ocean. The fate of phytoplankton in the open ocean is predominately recycling through the microbial food web, with relatively low sedimentation compared to the coastal ocean. Therefore, the two distinct oceanic regimes have different phytoplankton dynamics resulting in different seasonality, algal community structure and fates of the phytoplankton carbon. These differences will strongly influence the biogeochemical signatures of the coastal and open oceanic NE subarctic Pacific.

Internal Tides in the Columbia River Plume Area

David A. Jay (Center for Coastal and Land Margin Research, Oregon Graduate Institute, Portland, OR) and Barbara M. Hickey (Oceanography Dept., University of Washington, Seattle, WA)

The buoyant plume of the Columbia River provides strong and highly variable stratification that supports a robust internal tide. Observations in the estuary entrance show semidiurnal (D_2) velocity amplitudes of $O(2\ \mathrm{ms}^{-1})$ with internal amplitudes of $O(1\ \mathrm{ms}^{-1})$. Mean tidal current amplitudes drop within a tidal excursion of the mouth to 0.05 to 0.25 ms^{-1}, still somewhat larger than typical shelf internal tides in the area. Continuous wavelet transform (CWT) tidal analysis methods have been used to analyze acoustic Doppler current profiler (ADCP), wind and density observations within the plume area during the National Science Foundation (NSF) supported Columbia River Plume Experiment (winter 1990-91). Plume internal tides are:

- highly non-stationary and episodic—major river-flow events create stratification to support the internal tide, but the storms that precede flow events destroy stratification through mixing and advect the plume away from its typical winter position (north along the

Washington Coast), within which most of our instruments were situated.

- primarily first mode and strongly non-linear — D_2 currents are typically a factor of two to three larger than diurnal (D_1) currents. Non-linear overtides (terdiurnal or D_3 and quarterdiurnal or D_4) are 50-100% as large D_1 currents, and 25-50% as large as D_2 currents. This strong non-linearity reflects plume internal tide generation mechanisms.
- part of a dynamical continuum with the subtidal rather than a series of spectrally discrete processes at most times and places. In addition to the spectrally discrete, remote forcing of internal tides, variations in windstress and density occur on time scales from 14 d to 1 d with about equal energy. Because D_1 is both weaker and closer (in frequency) to subtidal motions, it is expected to be relatively more strongly modified by non-tidal processes than the D_2, as is also seen in river tides.

Near the estuary mouth, D_4 and D_2 internal tides are in the mean phase-locked, as are D_3 and D_2, suggesting nonlinear generation. Thus, there are several active generation mechanisms. The first is the usual shelf-break one. Another is a top-to-bottom tidal excursion of the density interface at the estuary mouth. A third is barotropic flow over Astoria Canyon. Because flow in the estuary entrance is super-critical at most stages of the tide (internal Froude numbers ~1-10), the time-evolution of the density interface is complex, leading to nonlinear plume tides. The degree to the two topographic mechanisms contribute to non-linearity of plume internal tides is unknown.

INTERANNUAL VARIABILITY OF LIFE CYCLE TIMING OF THE COPEPOD NEOCALANUS PLUMCHRUS IN OCEANIC AND COASTAL WATERS OF THE NORTHEAST PACIFIC

David L. Mackas (Institute of Ocean Sciences, Fisheries & Oceans, Sidney, B.C.), R. Goldblatt and E. Bornhold (Dept. of Oceanography, University of British Columbia, Vancouver, B.C.)

In both oceanic and deep coastal waters of the North Pacific, copepods in the genus Neocalanus dominate the spring and early summer mesozooplankton community. Neocalanus species undergo a very strong seasonal vertical migration that is closely linked to their developmental cycle. In the upper 150 m at both Ocean Station P (50° N, 145° W) and in the Strait of Georgia (49-50° N, 123-125° W), the 30–50 day annual peak of mesozooplankton biomass has historically coincided with maximum surface layer abundance of maturing Neocalanus plumchrus copepodites (C4 and pre-migrant C5). We present evidence for large amplitude and large spatial-scale shifts in the timing of the N. plumchrus life cycle during the past 25–30 years. At Ocean Station P, completion of development to down-migrant C5 is now about 40–50 days earlier than in 1971 (late May-early June vs. mid-late July). In the Strait of Georgia, the developmental cycle is about 25–30 days earlier (early May vs. early June). The variability in timing is coincident with warming trends of both surface and over-wintering-depth deep water in both regions, and is likely to be ecologically significant because it shifts relatively narrow seasonal windows of maximum grazing pressure on 10–50 micrometer prey, and of availability of large copepodites to upper ocean predators such as sockeye salmon, herring and hake.

LARGE SCALE FORCING ON THE NE PACIFIC MARINE ENVIRONMENT

Nathan Mantua (Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, WA)

In this study I examine past variations in the physical characteristics of the coastal waters of the NE Pacific Ocean. I compare and contrast this regional variability to that at the Pacific basin scale, and also to known changes in coastal marine ecosystems of the NE Pacific Ocean.

From a Pacific Basin scale perspective, a restrospective analysis identifies a pair of related recurring patterns: one associated with the preferentially interannual El Niño/Southern Oscillation (ENSO) cycle, and the other related to the lower frequency Pacific Decadal Oscillation (PDO).

Several recent studies have identified temporal coherence between variations in some NE Pacific marine ecosystems and the PDO. However, the time history of the PDO is not always in lock-step with known indicators for Pacific marine ecosystems, nor with the coastal marine environment of the NE Pacific.

By adopting an analysis strategy based on a regional perspective, I identify the large-scale climate patterns that contribute most strongly to variations in the coastal marine environment of the NE Pacific Ocean.

I conclude with a discussion of the 1997 spring/summer large scale climate conditions that have contributed to the development of anomalous conditions in the coastal ocean and ecosystems of the NE Pacific.

NORMAL MODE ANALYSIS OF DYNAMIC HEIGHT IN THE GULF OF ALASKA

Heather D. Hunt and David L. Musrave (University of Alaska, Fairbanks, AK; H. Hunt *now at Woods Hole Oceanographic Institution, Woods Hole, MA)*

The seasonal cycle of dynamic height, its relationship to seasonal wind stress curl, and the propagation of interannual dynamic height anomalies in the Gulf of Alaska are described using STD/XBT-derived dynamic height and COADS wind stress data for the period 1968-1990. Singular Value Decomposition analysis of the seasonal dynamic height and wind stress curl fields resulted in a first mode, that contained 71% of the total seasonal variance, with spatial and temporal characteristics consistent with Ekman pumping dynamics. Complex Empirical Orthogonal Function analysis was applied to dynamic height anomalies (seasonal mean removed) yielding four physically significant modes. These four modes represented cyclonic shift from low to high dynamic height during the 1970's to the 1980's, northwest-southeast motion that intensified and then diminished gyre circulation, large-scale westward diversion of flow that cycles every 6-7 years, and a 3-4 year period travelling wave in the Alaska Current and the Alaska Stream.

EPOC Poster Session

ABSOLUTE GEOSTROPHIC FLOW IN THE CALIFORNIA CURRENT OFF SOUTHERN CALIFORNIA USING ADCP REFERENCED HYDROGRAPHY

Alana M. Althaus and Teri K. Chereskin (Scripps Institution of Oceanography, La Jolla, CA)

Direct velocity observations from shipboard acoustic Doppler current profiler (ADCP) measurements have been obtained on hydrographic cruises made by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) since October 1993. We use the hydrographic and ADCP observations, together with an objective analysis method, to map the absolute geostrophic flow at the surface and at 500 m for a sequence of the CalCOFI quarterly cruises, from October 1994 to April 1996. We find that there is significant flow at 500 m, the traditional level of no motion imposed by the maximum depth of CalCOFI hydrographic sampling. The pattern of flow at 500 m is generally coherent with the surface flow field. The absolute surface geostrophic flow is on average about 35% larger than would be obtained assuming a level of no motion at 500 m.

SOME UPWELLING CHARACTERISTICS OFF SENEGAL (WEST AFRICA)

Bassirou Diaw (College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR)

As in other eastern boundaries under the influence of the trade winds, a dominant future along the Northwest African continent is coastal upwelling of cool and nutrient-rich subsurface water, which causes high biological productivity on the shelf. The average width of the shelf off Northwest Africa, between the Strait of Gibraltar and Cap-Vert Peninsula (Senegal), is about 50 to 60 km. Off senegal, the wind-driven upwelling can be modified by the shelf topography.

The Cap-Vert peninsula divides the coast in north part (Grande Cote) and south part (Petite Cote) having different hydrodynamic behavior. Because of a different orientation of the coastline in both side, upwelling intensity will differ in these two areas. During periods of weak trade-wind intensity, the upwelling is weaker north of peninsula than south. During periods of high trade-wind intensity, similar upwelling intensities are observed in the two areas. North, the upwelling is trapped next to the coast; south, the upwelling is at the shelf margin and is stronger and longer in duration.

We calculate some upwelling characteristics north and south of Cap-Vert peninsula (Ekman transport, surface and vertical velocities, and coastal upwelling index), to compare the north and the south part of the coast.

We use wind data and sea surface temperature of the period 1993 to 1995, from the coastal stations of Yoff (in the north part) and Mbour (in the south part). We use also current and temperature data from Aanderaa moorings off Mbour for the same period. We present some spectral characteristics of the data.

DESIGN OF A COASTAL OCEAN LAGRANGIAN (COOL) FLOAT

D. Hebert, M. Prater, J. Fontaine, J. Rajamony and H.T. Rossby (Graduate School of Oceanography, University of Rhode Island, Narragansett, RI)

With the support of the Office of Naval Research, a COastal Ocean Lagrangian (COOL) float is being designed as a truly three-dimensional Lagrangian follower of water parcels. It incorporates the features of the isopycnal f/h float which can change its volume (density) and an isobaric vertical current meter (VCM) float. Water flowing vertically past the vanes on the VCM floats rotates it. Measuring the rotation rate of the float would provide a measure of the vertical velocity. Likewise, vanes on the COOL float would rotate the float. However, the isopycnal COOL float would respond to diapycnal velocities past it instead of vertical velocities.

Although VCMs have been previously developed and deployed, not much was known about how the geometry of the vanes affects the float's response to vertical velocity. From tank studies, we determined that the sensitivity (i.e., the ratio of the float's rotation rate to vertical velocity past it) increased with decreasing distance of the vanes from the body of the float and decreasing angle of the vanes to the horizon. In the tank studies, the minimum vertical velocity with which we obtained reliable results was approximately 0.5 cm/s.

We will present results from a recent test cruise. Both isobaric and isopycnal floats were used. The use of the float's VOCHA (volume changer) and pressure sensor allows us to determine the sensitivity at small vertical velocities. We will also present the float's response in the presence of an internal wavefield.

OBSERVATIONS OF HIGH FREQUENCY INTERNAL WAVES OFF OF MISSION BEACH, CA

James Lerczak, Myrl Hendershott and Clinton Winant (Scripps Institution of Oceanography, La Jolla, CA)

Data from a coherent array of moorings in depths ranging from 15 to 30 m off of Mission Beach, CA are used to study the behavior of high frequency internal waves. The array consisted of bottom-mounted ADCP's and temperature loggers strung along the mooring line. In addtion, CTD yoyo's were conducted to obtain stratification data. The data are consistent with predominantly mode one waves propagating onshore with nearly normal angles of incidence. The high frequency internal wave signal is intermittent, but does not appear to be coupled to the surface tide. Packets of internal waves observed at the farthest offshore mooring are linearly propagated onshore using WKB theory. Comparisons are made with data from the inshore moorings to obtain dissipation and angle of incidence estimates for the packets.

SEASONAL VARIABILITY OF THE NORTH PACIFIC EASTERN BOUNDARY CURRENTS SYSTEM BASED ON CLIMATOLOGICAL DATA AND THE PRINCETON OCEAN MODEL

Grigory Monterey (JIMAR, University of Hawaii, Honolulu, HI; presently at PFEG/-NMFS/NOAA, Pacific Grove, CA)

The Princeton Ocean Model (POM) was originally developed for high resolution coastal applications and later extended to regional scale. It has been proven to perform well in areas over steep continental slope and to approach equilibrium solution (mid latitudes) in 7-10 days of simulated (not CPU) time. Present implementation is for the North Pacific from 10˚–62˚ N with 1˚ x 1˚ spatial resolution. This resolution is not adequate in coastal areas and has to be increased. The model is run on a Silicon Graphics workstation. Its spatial resolution is limited by currently available Random Access Memory. The POM is run in diagnostic mode, i.e., with forcing fields held fixed in time, and solves for the velocity field which is in dynamic equilibrium with forcing fields. The model is run 12 times forced by monthly mean fields to simulate velocity fields for every month. Model input includes bottom topography and climatological monthly mean surface wind stress and subsurface temperature and salinity. Output includes vertically integrated transport and three-dimensional velocity field. Visualization of input and output data is based on graphical application language Ferret, which has zoom and animation capabilities and is compatible with Live Access to Climatic Data via Internet. Preliminary results show that Eastern Boundary Currents (EBC) are an integral part of the regional scale circulation, and are controlled by regional rather than local forcing. In winter the regional scale gyres including EBC appear to be more energetic than in summer.

DIURNAL SURFACE CURRENT FLUCTUATIONS IN MONTEREY BAY FORM CODAR-TYPE HF RADAR

Jeffrey D. Paduan, Leslie K. Rosenfeld, and Michael S. Cook (Dept. of Oceanography, Naval Postgraduate School, Monterey, CA)

Diurnal-period surface current fluctuations in the coastal waters of Monterey Bay are described based on measurements from a network of CODAR-type HF radar sites. Emphasis is placed on the summer-time conditions when diurnal sea breeze forcing dominates the near surface (~1m) HF radar measurements. The amplitude of diurnal current variations (~20 cm/s) is comparable to the strongest portions of the background circulation within Monterey Bay. Peak currents are directed onshore in the early afternoon immediately following onset of sea breeze forcing. Closer to shore, surface currents rotate clockwise out from under the wind forcing, and the entire diurnal surface current response decays offshore out to ~50 km, similar to the observed off-shore limit of sea breeze forcing. Mooring data show that the depth extent of the wind-forced diurnal fluctuations is limited to the upper few meters of the water column. Tidal analyses of month-long time series reveal different spatial patterns for the diurnal surface currents, which are dominated wind forcing, versus the semidiurnal surface currents, which are dominated by internal tides and the complicated local bathymetry.